Design and Operation of a Calorimeter for Advanced Multilayer Insulation Testing

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Background

- Need to obtain thermal performance data of various multi-layer insulation (MLI) packages at low temperatures to simulate the thermal environment underneath a broad area cooling (BAC) shield on a liquid hydrogen tank.
- Requires a test apparatus to subject the MLI to cold and warm boundary temperatures of 20K and 90K.
  - The cold temperature boundary represents the temperature of liquid hydrogen at its normal boiling point.
  - The warm temperature is the current design point for the operation of a BAC shield.
- Very low temperature calorimetry was done historically by the accelerator community, but has not been done for ~ 30 years.
  - Wide range of results
  - Advancements in measurement capabilities should improve our understanding of low temperature insulation behavior

Basic Design of Calorimeter

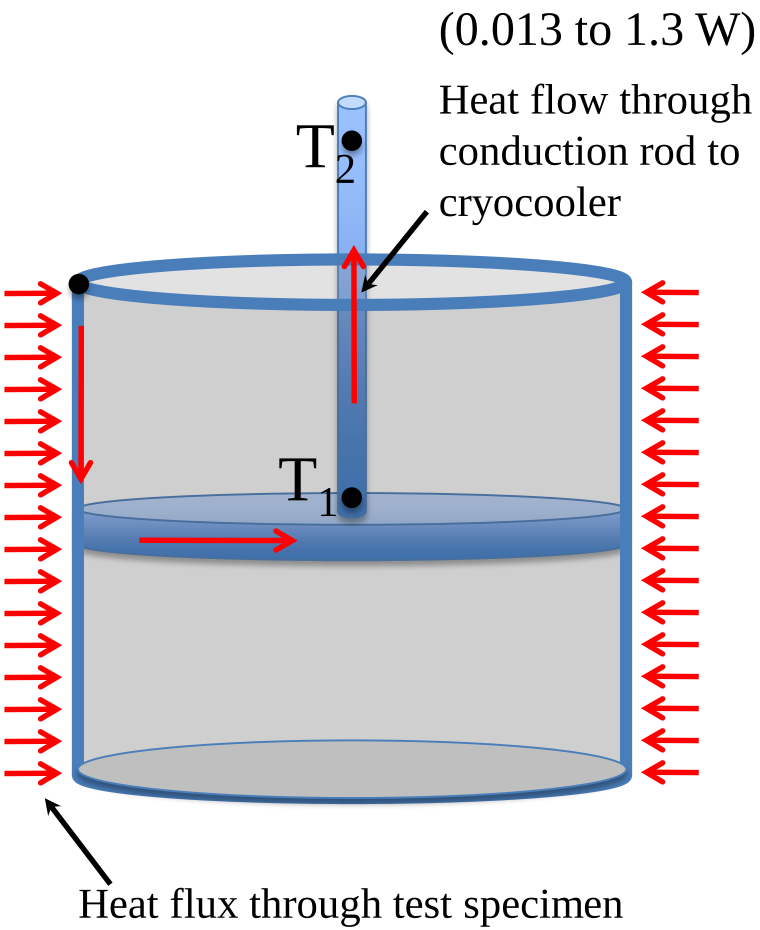
- Calorimeter was constructed to measure the performance of MLI using cryocoolers rather than cryogens.
- Key advantages include:
  - Not needing to use and top-off with cryogens,
  - Less safety restrictions on unattended operation and location of test rig since volatile cryogens are not present,
  - Wider range of boundary temperatures.
- Designed for boundary temperatures of 20K on the cold side and 90 K on the warm side
- Includes guards for top and bottom of measure cylinder
- Based on Conduction Rod system (explained on the next chart)

Calibrated Rod

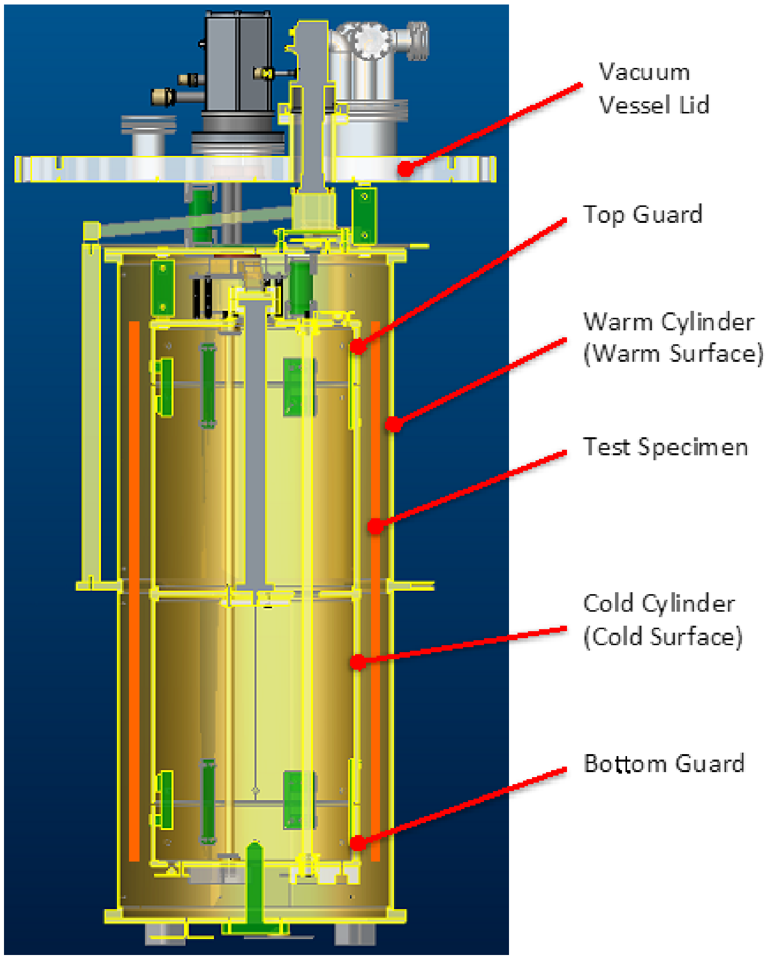
- Heart of the calorimeter – Measures heat flow through the measurement section (midsection of the cold cylinder)
  - Conduction rod has
    - hot end and cold end temperature sensors
    - known length between temperature sensors
    - known cross-sectional area
    - known material thermal conductivity
- Heat transfer rate calculated from Fourier conduction law

$$Q = \frac{kA}{L}\Delta T = \theta \Delta T$$

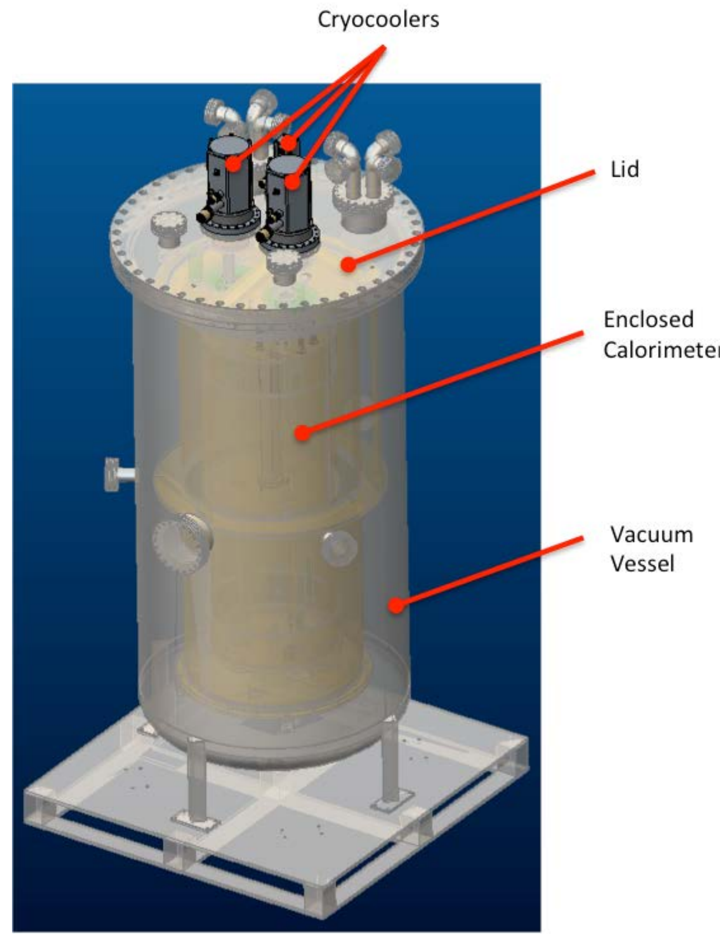
- Rod can be calibrated; k, A and L all temperature dependent
- Heat flux through MLI is heat transfer rate through conduction rod divided by MLI surface area



Concept Drawings of Calorimeter



Cut through

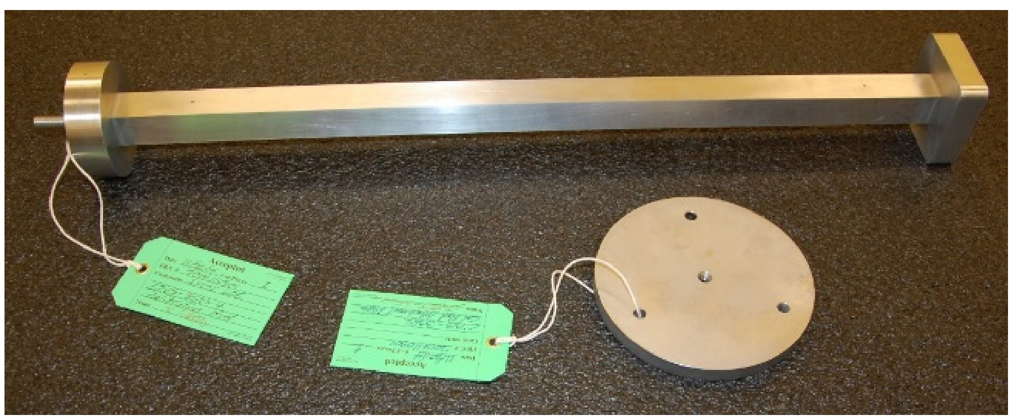


Installation in Vacuum Vessel

Inner and Outer Cylinders in preparation for test

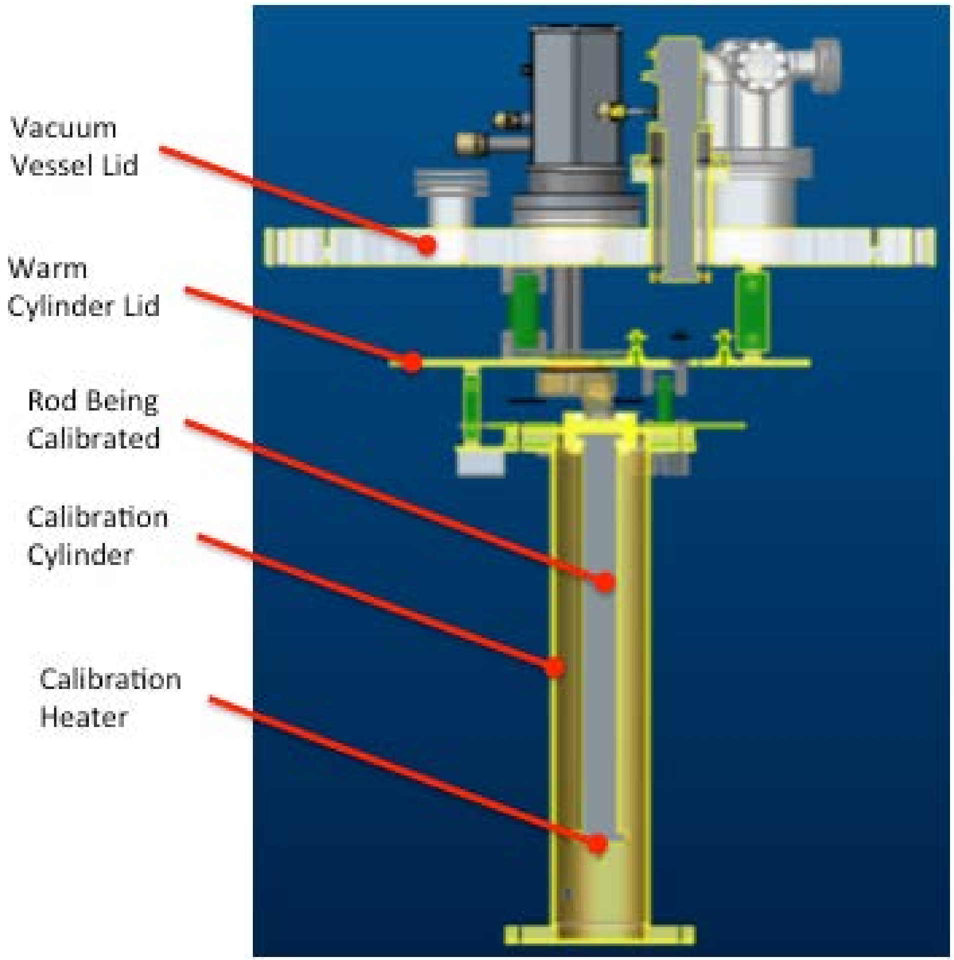
Cryocoolers and Conduction Rod

Cryocoolers Mounted on Vacuum Vessel Lid

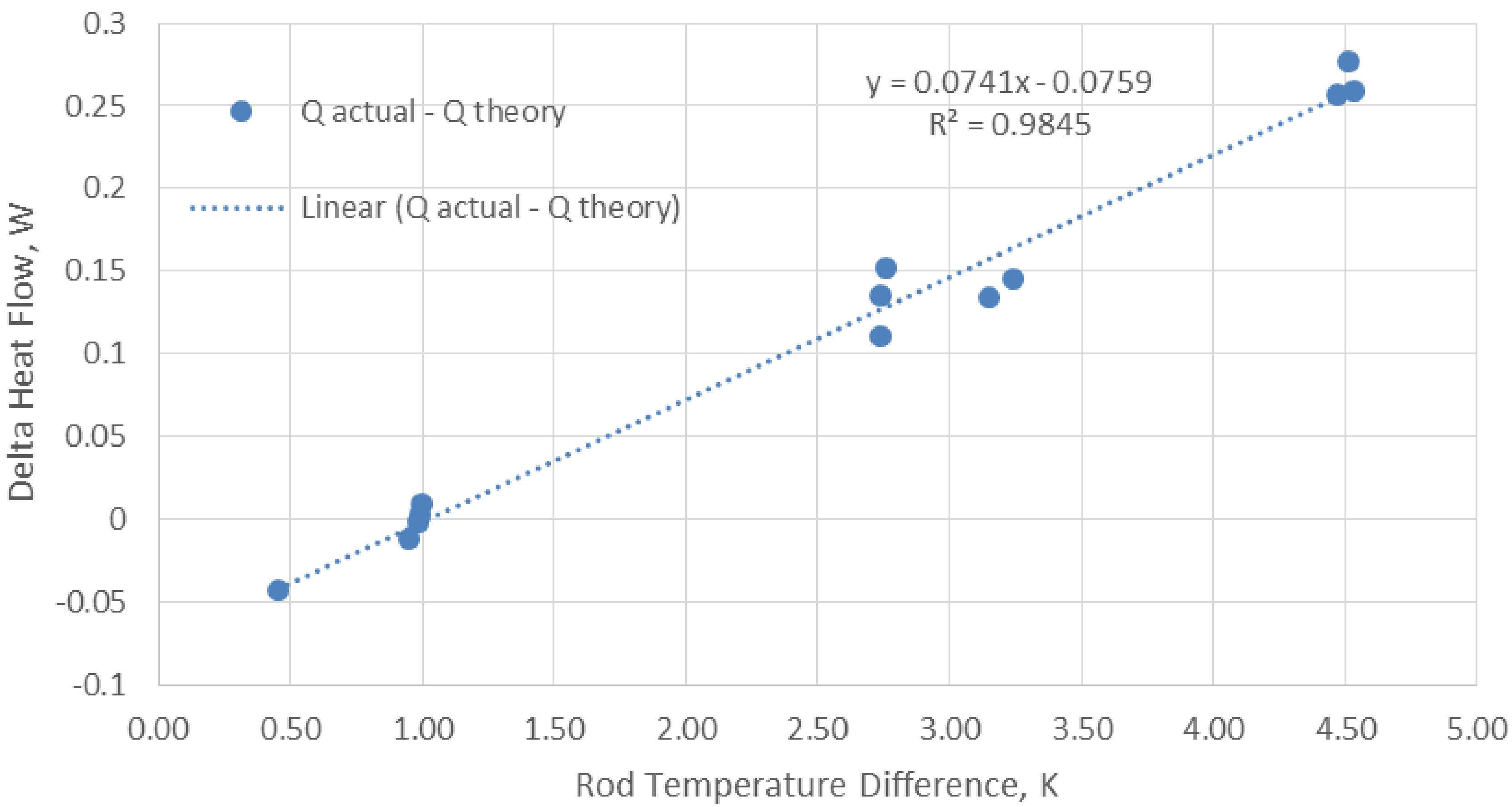


Calibrated Conduction Rod (Dash 4) and Adapter Plate

Calibration Rig



Difference between predicted and actual heat flow

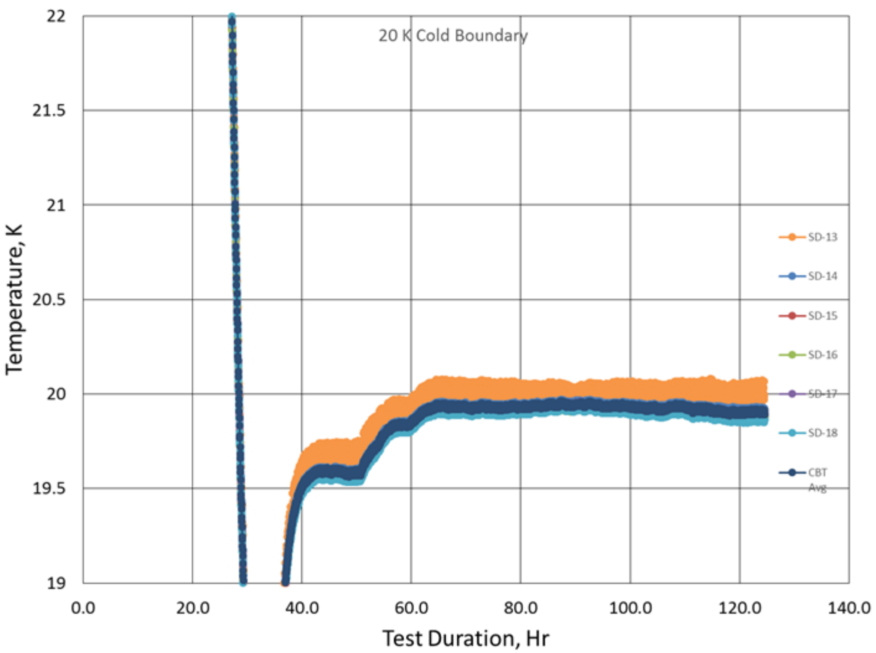


Calorimeter Testing

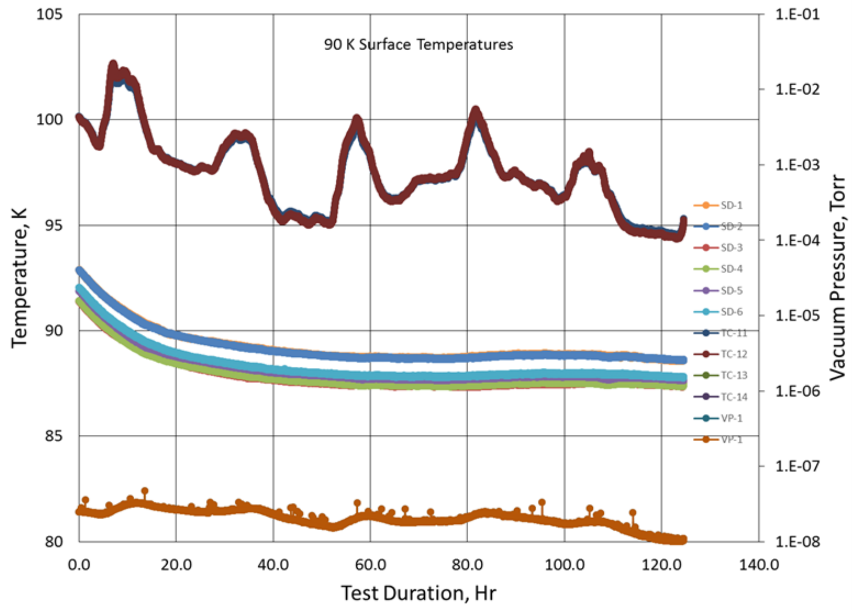
- Compare Aluminum Foil to Double Aluminized Mylar
    - 1 - layer
    - Foil should completely block transmission
    - If aluminized mylar similar performance, then transmission is not noticeable
    - Foil had slightly worse room temperature emissivity, but should improve more with temperature drop

	Test Specimen	Aluminum Thickness, μm	Warm Boundary Temperature, K	Cold Boundary Temperature, K	Vacuum Level, torr	Room Temp ε
Test 1	Aluminized Mylar	0.08 (on each side)	90	20	10^{-6}	0.013 +/- 0.003
Test 2	Aluminum Foil	7.2	90	20	10^{-6}	0.046 +/- 0.02

Test Data



20 K Cold Boundary
22
21.5
21
20.5
20
19.5
19
Temperature, K
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
Test Duration, Hr
SD-13
SD-14
SD-15
SD-16
SD-17
SD-18
CBT Avg



90 K Surface Temperatures
105
100
95
90
85
80
Temperature, K
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
1.E-07
1.E-08
Vacuum Pressure, Torr
0.0
20.0
40.0
60.0
80.0
100.0
120.0
140.0
Test Duration, Hr
SD-1
SD-2
SD-3
SD-4
SD-5
SD-6
TC-11
TC-12
TC-13
TC-14
VP-1
VP-1

Calorimeter Results & Calculations

Test Coupon	Vacuum Pressure (Torr)	Warm Boundary (K)	Cold Boundary (K)	SD-31 (K)	SD-34 (K)	Calculated Heat Load (mW)
Aluminum Foil	2.2×10^{-8}	87.1	20.1	16.77	19.80	281
Aluminum Foil	2.2×10^{-8}	107.2	20.4	16.80	20.07	306
Aluminized Mylar	1.8×10^{-8}	87.8	19.9	18.07	20.04	190
Aluminized Mylar	1.2×10^{-8}	107.8	20.2	18.08	20.21	207

Test Coupon	Warm Boundary (K)	Qnet (mW)	Heat Flux (mW/m^2)	Effective emissivity
Aluminum Foil	87.1	132	93	0.028
Aluminum Foil	107.2	152	107	0.014
Aluminized Mylar	87.8	66	46	0.014
Aluminized Mylar	107.8	81	57	0.007

Assessment of Results

- Any transmissivity in the DAM vis-a-vis the aluminum foil should show as a higher heat load in a low boundary temperature test.
- Our test results consistently show a lower heat load for DAM than aluminum foil.
- Based on this data it is unlikely that any increase heat load at low temperatures can be attributed to transmission through DAM

Summary

- A new calorimeter for testing cryogenic insulation has been successfully constructed and is now operational.
- Work on single layer transmissivity has indicated that the long held speculation that DAM might be transparent at low temperatures may be incorrect.
- Direct transmissivity measurements of DAM samples are under way as well, to further validate these findings.
- Further testing with full multilayer insulation blankets and different seaming techniques is planned in the near future.

Thank you to the IFUSI team for their assistance!